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Exposure to Pollutants from Domestic Combustion Sources
A Preliminary Assessment

TRC Environmental Consultants, Inc.
Wethersfield, CT

Prepared for

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16. ABSTRACT The report gives results of a preliminary assessment of exposure to pollutants from domestic combustion sources, some of which emit airborne particulate matter (PM), CO, and polycyclic organic matter (POM) near human receptors. Transient ambient concentrations of these pollutants at the receptor (and the corresponding time-averaged exposures) have been determined for the following domestic combustion sources: lawn mowing, chain sawing, charcoal cooking, indoor gas cooking, and indoor side-stream smoke. An experimental test program utilizing personal monitoring equipment was conducted to acquire data for the lawn mower, chain saw, and charcoal grill sources. Literature data were used to assess the indoor sources of gas cooking and side-stream smoke. Transient ambient concentrations of total suspended particulate (TSP) matter encountered were as high as 35 times the 24 hour secondary ambient air quality standard of 150 micrograms/cu m for TSP. However, large quantities on noncombustion-related PM on the filters (e.g., grass particles, sawdust), concurrent lower values of ambient CO relative to ambient air quality CO standards, and the absence of detectable POM indicate that these sources probably do not result in exposures to combustion-generated pollutants that are relatively significant.

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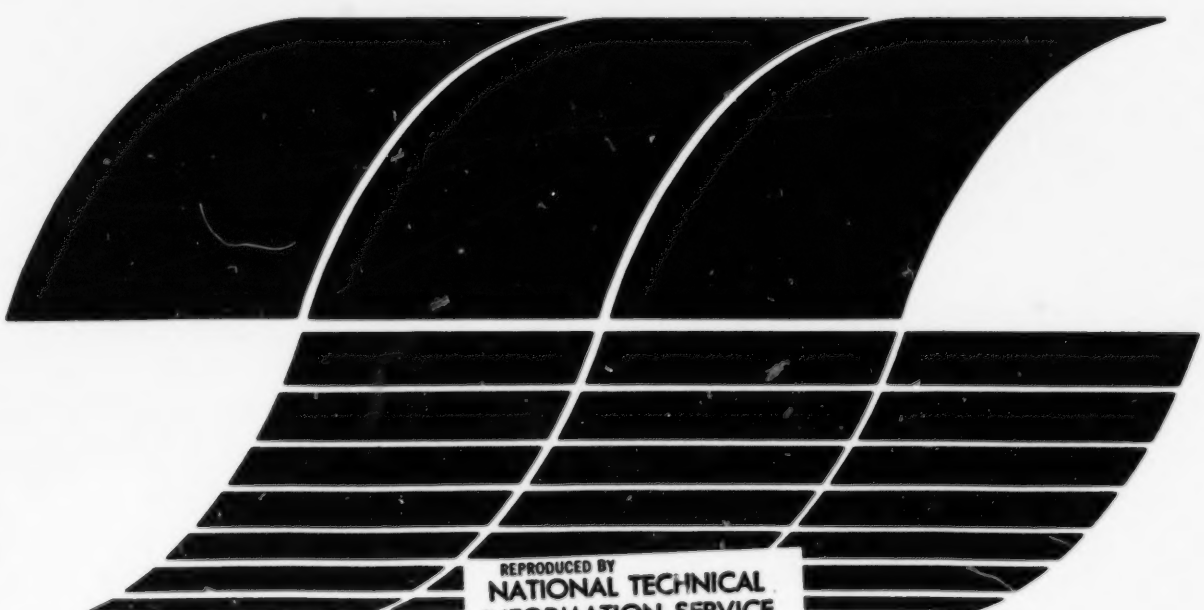

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Exposure to Pollutants from Domestic Combustion Sources: A Preliminary Assessment

by

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ABSTRACT

Certain domestic combustion sources emit airborne particulate matter (PM), carbon monoxide (CO), and polycyclic organic matter (POM) in close proximity to human receptors. The transient ambient concentrations of these pollutants at the receptor and the corresponding time-averaged exposures have been determined for the following domestic combustion sources: lawn mowing, chain sawing, charcoal cooking, indoor gas cooking, and indoor sidestream smoke. An experimental test program utilizing personal monitoring equipment was conducted to acquire data for the lawn mower, chain saw, and charcoal grill sources. Literature data were utilized to assess the indoor sources of gas cooking and sidestream smoke. The transient ambient concentrations of particulate matter encountered were as high as 36 times the 24-hour secondary ambient air quality standard of 150 $\mu g/m^3$ for TSP. However, the presence of large quantities of noncombustion-related particulate matter on the filters (e.g., grass particles, sawdust), concurrent lower values of ambient CO relative to ambient air quality CO standards, and the absence of detectable POM indicated that these sources probably do not result in exposures to combustion-generated pollutants that are significant relative to exposures that would be encountered in general TSP non-attainment areas that are heavily impacted by stationary and mobile combustion sources.

CONTENTS

Abstract ii

1. Introduction 1
2. Exposures from Indoor Combustion Sources 3
3. Exposures from Small Internal Combustion Engines and Charcoal Grills 14
4. Comparison of Exposures. 29
5. Conclusions and Recommendations 36
6. References. 39

FIGURES

Number		Page
1	Time Variation of Carbon Monoxide Concentrations in a Typical Split-Level Dwelling	4
2	Schematic of Sampling System Used for Domestic Combustion Field Tests	16
3	Average CO Concentrations from Charcoal Grills as a Function of Time	26

TABLES

Number		Page
1.	Summary of Pollutant Emissions of Gas Appliances for Several Typical Operating Conditions	6
2.	Ratio of Sidestream to Mainstream CO Emission - Experimental Results	8
3.	Aromatic Hydrocarbons Identified in Tobacco Smoke	10
4.	Number Concentration and Average Size of Particles Contained in Tobacco Smoke	11
5.	Domestic Combustion Field Test Parameters - Lawn Mowers	18
6.	Domestic Combustion Field Test Parameters - Chain Saws	19
7.	Domestic Combustion Field Test Parameters - Charcoal Grills	21
8.	Carbon Monoxide Results from the Experimental Test Program	24
9.	Particulate Results from the Experimental Test Program	27
10.	Source Usage Patterns Based on TRC Questionnaires	30
11.	"Typical" Exposures to Carbon Monoxide from Domestic Combustion Sources	32
12.	"Typical" Exposures to Particulate Matter from Domestic Combustion Sources	34

SECTION 1

INTRODUCTION

Over the past several years, it has been realized that ambient air quality, which is frequently measured by only a few monitoring stations in a large geographical area, may not describe adequately the exposure of the population at large to air pollutants. As one means of understanding the true situation, the Environmental Protection Agency (EPA) is conducting a Conventional Combustion Environmental Assessment (CCEA) program that is directed at assessing emissions and their associated impacts from utility, industrial, commercial, and residential combustion processes. The emphasis of the CCEA Program is on traditional point and area sources (e.g., smoke stacks, material handling, industrial processes, automobile exhaust) that emit pollutants in quantities that significantly impact general ambient air quality.

This assessment of conventional sources has led to the question of the exposure to combustion products resulting from several common domestic combustion processes. Several readily identifiable "sources" in this category are indoor gas cooking, food spills on heating elements, sidestream smoke from cigars and cigarettes, gas-fired laundry driers, space heaters, small internal combustion (IC) engines such as those in chain saws and lawn mowers, and backyard charcoal cooking. Although the total emissions from these non-conventional domestic combustion sources are relatively small and are not expected to contribute significantly to general ambient air levels of combustion-related pollutants, the exposures resulting from these sources, which are often "close up" to the receptor, may be significant in comparison to exposures resulting from emissions from the more conventional large point and area combustion sources.

TRC-The Research Corporation of New England was contracted by the Environmental Protection Agency's Industrial Environmental Research Laboratory at Research Triangle Park (EPA/IERL/RTP) to estimate exposures to airborne contaminants resulting from domestic combustion sources, and to compare these to exposures generated by conventional combustion sources that affect the general air quality. In particular, exposures to total particulate matter (PM), carbon monoxide (CO), and polycyclic organic matter (POM) resulting from indoor combustion sources, small IC engines, and charcoal cooking were to be determined. This report presents the results of this exposure study in the following manner:

- For the indoor air pollution case, exposures were determined primarily by extracting and analyzing information from previous studies on indoor air pollution. Specific sources addressed under this category included

gas cooking and sidestream smoke. Section 2 describes the results of this literature search.

- For the small IC engines and charcoal cooking categories, an experimental program was designed and implemented for the purpose of determining exposures to PM, CO, and POM. The sampling technology used consisted of personal monitoring systems. The sources investigated included lawn mowers, chain saws, and charcoal grills. Section 3 describes this experimental program and the laboratory procedures required to determine the exposures, and presents the results of the testing.

- Section 4 presents "typical" exposures to domestic combustion sources and compares these to exposures from other conventional sources. The "typical" exposures were determined using the results of the literature search and test program in conjunction with estimated source usage patterns obtained from literature data and questionnaires.

- The conclusions and recommendations derived from this study are presented in Section 5 and the references cited in the text are given in Section 6.

SECTION 2

EXPOSURES FROM INDOOR COMBUSTION SOURCES

The typical American spends the majority of his waking hours indoors. Much of this time may be spent in the presence of unvented combustion sources such as gas cooking and cigarette smoking which are major contributors to indoor air pollution. This section summarizes a literature review on the contributions of gas cooking and cigarette smoking to the indoor concentrations of CO, PM, and POM.*

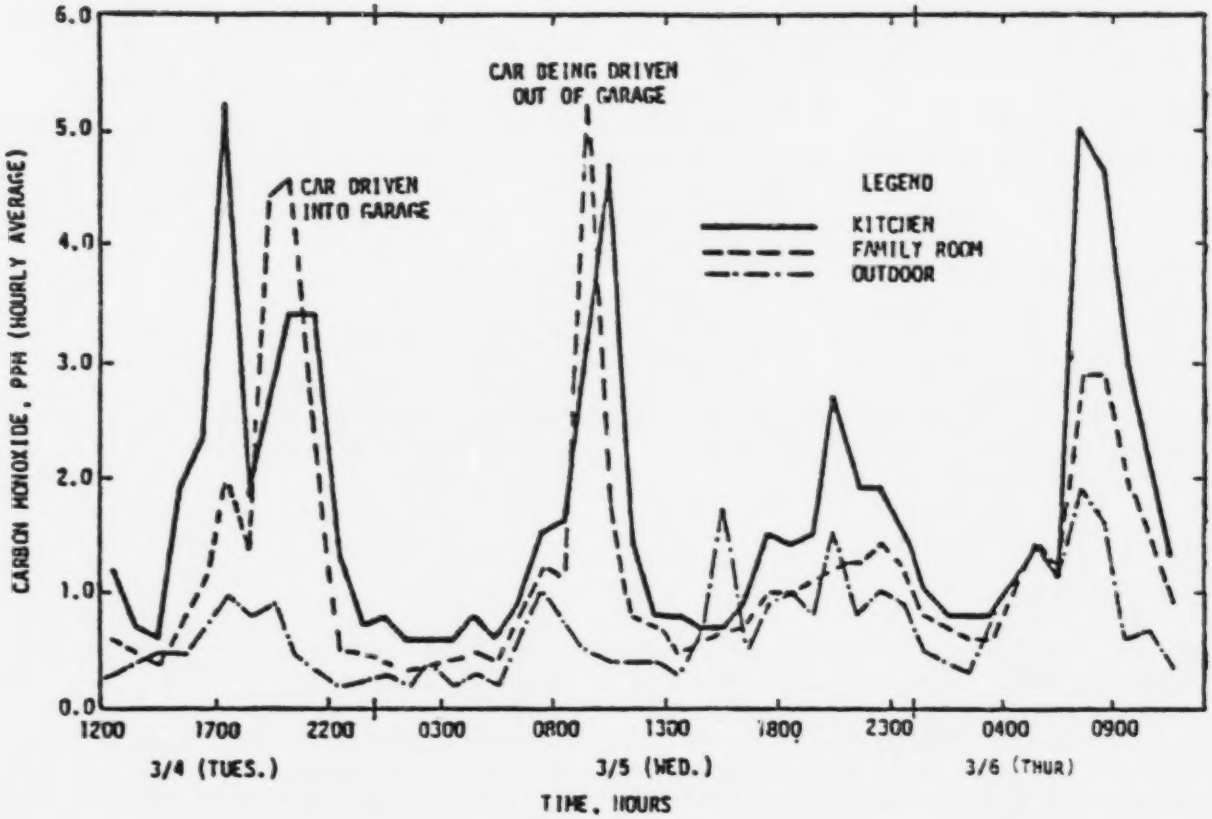
CARBON MONOXIDE

Carbon monoxide is generated as a result of the incomplete combustion of carbonaceous materials. In the outdoors, the main source of CO is the exhaust from motor vehicles. Indoors, CO can be formed by combustion associated with gas ovens and stoves, cigarette smoking, space heaters, fireplaces, and spills on heating elements. The two major CO sources, gas ranges and cigarettes, are discussed below.

Gas Ranges

A study of indoor-outdoor air pollutant relationships was the subject of a report by Yocom, Cote and Clink.[1] Figure 1, taken from this report, shows the combined effect of several indoor and outdoor sources on the indoor concentration of CO, and on its indoor spatial and temporal distribution. The effect of cooking (3/4-1800 and again on 3/5-2000 and 3/6-0800), operating a motor vehicle inside the garage having a common door with the house (3/4-2000 and 3/5-0900), and increased outdoor concentration, presumably due to an increase of traffic density (3/5-0800 and 1600-1700 and on 3/6-0600), are clearly seen. It should be noted that the indoor concentration of CO is substantially higher than the outdoor concentration most of the time. It is also interesting to note that increased CO concentration in the kitchen (presumably as a result of cooking) does not substantially affect the CO concentration in the family room. The authors reported that this house was a split level house with the kitchen elevated above the family room. This emphasizes the importance of the effect of the layout of the

*POM is also referred to as PAH (polynuclear aromatic hydrocarbons) since PAH is the major subcategory of POM. These two terms are used interchangeably throughout the report, depending on the reference cited.



Source: Yocom, Cote, and Clink[1]

Figure 1. Time Variation of Carbon Monoxide Concentrations in a Typical Split-Level Dwelling

houses on the exposure of its occupants to air pollutants. Similar results on the relation between indoor and outdoor concentration of carbon monoxide were reported in a study by Moschandreas.[2]

Emission rates of domestic gas stoves and ovens were measured in a study by Cote, Wade and Yocom.[3] Their results are presented in Table 1. Other studies have shown that the emission rate increases as the oxygen supply decreases; i.e., by operating more than one burner and/or by placing a utensil on the burner.[4,5,6] In airtight buildings, where the ventilation rate is low, the rate of CO production can increase substantially after prolonged operation of gas stoves and ovens, as the normal air oxygen concentration inside the building decreases from approximately 21% to 20% or lower.[5]

Sidestream Smoke

Smoking is another source of indoor carbon monoxide and several researchers have measured CO emissions from cigarette smoking. Because the various studies were done under different conditions (smoking machines vs. humans, various room or test chamber volumes and ventilation rates, number of cigarettes and total length of time smoked), it is difficult to make valid comparisons among the various data.

The non-smoker is exposed to the pollutants that are present in the sidestream smoke (i.e., the smoke that comes from the smoldering end of the cigarette and that fraction of the mainstream smoke which is exhaled by the smoker). The exhaled portion contains some fraction of the pollutants contained in the mainstream smoke. Hattori and Ro[7] reported that 5 mg of CO per minute are emitted into the atmosphere just from the burning of a cigarette. When the smoker inhales, the amount of CO emitted in the exhaled smoke is reduced to about 12% of the 5 mg amount or 0.6 mg per minute. Hoegg[8] reported that this fraction can be as much as 45%.

Several studies were conducted in which CO concentrations were measured in rooms and test chambers. Penkala and Olivera[9] measured a concentration of 21 ppm of CO in a test chamber of 9.175 m^3 after three cigarettes were smoked by a smoking machine. Both the sidestream and mainstream smoke were introduced into the chamber. Harke et al[10] recorded 21 ppm of CO in a 170 m^3 room after 108 cigarettes were smoked by 11 people during 2 hours. This study cannot be considered realistic since it was undertaken to determine whether the CO concentration can reach a dangerous level under extreme conditions. Under more realistic conditions, Bridge and Corn[11] reported that during a party in a 100 m^3 room with a ventilation rate of 10.5 air exchanges per hour, the average CO concentration in the room over a 1.5 hour time span was 9 ppm. A total of 63 cigarettes and 10 cigars were smoked during the party.

In order to assess the relative exposure to CO of the non-smoker to the smoker, the ratio of sidestream CO emissions to mainstream CO emissions was

TABLE 1. SUMMARY OF POLLUTANT EMISSIONS OF GAS APPLIANCES FOR SEVERAL TYPICAL OPERATING CONDITIONS

Appliance	Operation	Heat Input Rate, kcal/hr	CO Emission Factors, mg/kcal	CO Emission Rate, mg/hr
Older Gas Stove with Cast Iron Burners	Pilot Lights	150	419	62.9
	1 Burner-High Flame	2700	382	1031
	3 Burners-High Flame	6780	475	3220
	Oven-Steady-State	2200	530	1166
Newer Gas Stove with Pressed Steel Burners	Pilot Lights	100	842	84.2
	1 Burner-High Flame	3500	510	1785
	3 Burners-High Flame	10200	315	3213
	Oven-Steady-State	2200	1620	3564

Source: Cote, Wade, and Yocom[3]

measured by several investigators. Their results are summarized in Table 2. The results suggest that as much as 4.6 times as much CO originates from the sidestream smoke as from the mainstream smoke.

Based on CO emitted in the sidestream smoke, Hoegg[8] calculated that the non-smoker in the room is exposed to 0.13-0.21 cigarette equivalents per cigarette smoked. The cigarette equivalent exposure depends on the room size, ventilation rate, and the number of cigarettes smoked per unit time.

PARTICULATES AND POLYCYCLIC ORGANIC MATTER

The concentration of gaseous pollutants in the atmosphere may be fully characterized by a single concentration value (expressed as ppm, $\mu g/m^3$ or other convenient measurement unit). Unlike gaseous pollutants, the concentration of particulate matter in the atmosphere cannot be characterized in a similar manner; many parameters are needed to describe the physical and chemical properties of the atmospheric aerosol. For example, information needed to characterize and quantify particulate matter in the atmosphere can include total particulate loading (expressed as $\mu g/m^3$), total number concentration (expressed as cm^{-3}), size distribution, mass or number concentration in the various size ranges, and detailed chemical analyses of the particles in the different size ranges. Obtaining all this information is a formidable and expensive task since no one instrument is capable of sampling and characterizing the atmospheric particles across the entire size range. For this reason there are very few studies which fully characterize outdoor atmospheric aerosols.

In most studies of indoor particulate concentration, the measured quantities were total suspended particulate matter measured by a low volume sampler.[15-21] In most cases, indoor concentrations were lower than outdoor concentrations. The means of the indoor/outdoor ratios measured by various researchers ranged from .15 to 1.3. The ratio varied from day to day and depended on the house structure, the occupants' activities, ventilation rate, etc.

In other indoor studies, the measured quantities were soiling index[22,23] and particle mass and number concentrations.[24-29] The ratio of indoor/outdoor for number concentratons of particles ranges from .45 to 3.8. The particle mass of the outdoor atmosphere particulate loading is concentrated in the larger particle sizes while number concentration has a maximum at 0.1 μm[30] and decreases toward the larger sizes. Apparently, the relative contribution of the small particles to the total particulate matter indoors is larger than such contribution outdoors. This conclusion was confirmed in the study by Yocom[18] where it was found that the indoor/outdoor ratio of total suspended particulates in two air conditioned office buildings in Hartford, Connecticut, was 1:2, while the indoor/outdoor ratio for respirable particles was about 2:3. Furthermore, more than 90% of the particulate loading of the indoor aerosol was in the respirable range (less than 2-3 μm in diameter); in effect, the air conditioning system removed almost all of the larger particles while having little effect on the smaller particles.

TABLE 2. RATIO OF SIDESTREAM TO MAINSTREAM CO EMISSIONS - EXPERIMENTAL RESULTS

Reference	Mainstream Emissions, mg/cigarette	Sidestream/ Mainstream
Bridge and Corn[11]	-	4.6
Sporozolini and Savino[12]	-	0.17
Rosanno and Owens[13]	23	2.75
Hemperley[14]	13.4	1.3-2.5

Combustion processes such as gas cooking and cigarette smoking contribute to the indoor concentration of particulate matter[16,19,22,31] with cigarette smoke being the major contributor to the indoor respirable particles.[32] As a result, the indoor aerosols are enriched in carbonaceous compounds.[19,22]

Reports on detailed analyses of indoor aerosols are scarce. In one report,[22] the authors stated that indoor aerosols were enriched in benzene-soluble compounds relative to outdoor aerosols. In a Bell Laboratory study,[33] a variety of organic compounds were identified in the indoor aerosols, including aliphatic alcohols, aliphatic acids, ethers, and organic phosphates.

No studies on the analysis of particles emanating from gas cooking were uncovered by the literature search but several studies dealing with the composition and size distribution of particles produced during smoking were reviewed. Stedman[34] stated that mainstream tobacco smoke contains 8% by weight of particulate matter with about 1200 different compounds identified. These include alkanes, alkenes, alkynes, ketones, aldehydes, alcohols, acids, esters, ethers, phenols, alkaloids, steroids, polynuclear aromatic hydrocarbons (PAH), various heterocyclic compounds (containing oxygen, nitrogen, and sulfur), and various metals. Snook et al[35] report that almost 1000 PAH have been identified in cigarette smoke condensate. A list of some of the various aromatic hydrocarbons identified in tobacco smoke is presented in Table 3. A number of PAH in tobacco smoke have been identified as active tumorogens[35] with the most active among them being benzo (a) pyrene (BaP).[34]

Several investigators measured the number concentration and size distribution of particles in cigarette smoke. A comparison of their results is difficult due to differences in the quantity measured (mean number or mean mass, median number or median mass) and differences in the techniques and instrumentation used. All of the investigators agreed that the number concentration of particles in cigarette smoke is more than a billion particles per cubic centimeter and the particles are in the respirable range. Table 4 summarizes the results of the various studies.

The exposure of the non-smoker to cigarette smoke depends on the number of cigarettes smoked per unit time, the room size, the ventilation rate, and the habits of the smoker. The non-smoker is exposed to the sidestream smoke and to that portion of the mainstream smoke that is exhaled by the smoker. Hoegg[8] reported that 50-70% of the mainstream particulate matter is exhaled into the atmosphere if the smoke is not inhaled. If the smoke is inhaled, 30% of the particulate matter is exhaled into the room.

Hemperley[14] reported that mainstream cigarette smoke from nonfilter cigarettes contains 27.9 mg/cigarette of dry particles with tar, the major constituent, contributing 20.8 mg/cigarette. Other constituents of the mainstream smoke are nicotine (0.92 mg/cigarette) and PAH (0.001 mg/cigarette). Hemperley also reported that the mainstream smoke contains 3.5×10^{-5} mg of benzo (a) pyrene and 1.3×10^{-4} mg of pyrene per cigarette.

TABLE 3. AROMATIC HYDROCARBONS IDENTIFIED IN TOBACCO SMOKE

Compound	Compound
Acenaphthene	Dimethylfluoranthene
Acenaphthylene	1,6-Dimethylnaphthalene
Alkylbenzo a pyrene	1,8-Dimethylnaphthalene
Alkylchrysene	2,6-Dimethylnaphthalene
Alkylfluorathene	2,7-Dimethylanaphthalene
Alkylpyrene	2,5-Dimethylphenathrene
Anthanthrene	Ethylbenzene
Anthracene	Ethylbenzene
Azulene	Ethyltolunes (o-,m-,p-)
Benz a anthracene	Fluoranthene
Benzene	Fluorene
Benzo b fluoranthene	Indene
Benzo g,h,i fluoranthene	Ideno 1,2,2-cd fluoranthene
Benzo j fluorathene	Ideno 1,2,3-pyrene
Benzo k fluorathene	Ionene
Benzo m,n,o fluoranthene	4-Isopropenyltolune
5H-Benzo a fluorene	Isopropylbenzene
11H-Benzo a fluorene	4-Isopropyltoluene
Benzo b fluorene	2-Methylanthracene
7H-Benzo c fluorene	9-Methylanthracene
11H-Benzo b fluorene	3-Methylbenz a anthracene
Benzo a naphthacene	5-Methylbenz a anthracene
Benzo g,h,i perylene	11-Methyl-11H-benzo a fluorene
Benzo c phenanthrene	Methylbenzo a pyrene
Benzo a pyrene	Methylchrysene
Benzo e pyrene	8-Methylfluoranthene
Biphenyl	1-Methylnaphtalene
Chrysene	2-Methylnaphthalene
Coronene	9-Methylphenanthrene
Dibenz a,h anthracene	1-Methylpyrene
Dibenzo a,i fluorene	2-methylpyrene
Dibenzo a,c naphthacene	4-Methylpyrene
Dibenzo a,j naphthacene	Methylstyrenes (o-,m-)
Dibenzo b,h phenanthrene	Naphthacene
Dibenzo a,h pyrene	Naphthalene
Dibenzo a,i pyrene	11H-Naphtho 2,1-afluorene
Dibenzo a,l pyrene	Naphtho 2,3-a pyrene
Dibenzo cd,jk pyrene	Perylene
9,10-Dihydroanthracene	Phenanthrene
5,6-Dihydro-8H-benzo a cyclopent h - anthracene	Phenylacetylene
	Pyrene
10,11-Dihydro-9H-benzo a cyclopent- i anthracene	Styrene
	Toluene
3,4-Dihydrobenzo a pyrene	Triben a,c,h anthracene
16,17-Dihydro-15H-cyclopent a - phenanthrene	1,2,3-Trimethylbenzene
	1,2,4-Trimethylbenzene
9,10-Dimethylbenz a anthracene	1,3,5-Trimethylbenzene
Dimethylchrysene	1,3,6-Trimethylnaphthalene
	Xylenes (o-,m-,p-)

Source: Stedman[34]

TABLE 4. NUMBER CONCENTRATION AND AVERAGE SIZE OF PARTICLES CONTAINED IN TOBACCO SMOKE

Particle Number Concentration, per cm^3	Average Particle Diameter, µm	Reference	Comments
-	0.18	Okada and Matsunuma[36]	Count median diameter Geometric standard deviation = 1.48 Dilution of 1500:1 Mainstream smoke.
-	0.21	Hoegg[8]	Mainstream smoke Particle size doubles in 4 minutes due to coagulation Total no. of particles emitted = $3.5 \times 10.^{12}$
-	0.15	Hoegg[8]	Sidestream smoke Total no. of particles emitted = $3.5 \times 10.^{12}$
6.3×10^9	0.15	Keith and Derrick[37]	Most frequently occurring Number of particles are particles emitted per second.
-	0.20-0.23	Keith and Derrick[37]	Most frequently occurring.
-	0.23	Keith and Derrick[38]	Count median diameter Geometric standard deviation = 1.69 Dilution of 295:1.
1×10^9 - 5×10^9	0.1-1.0	Stedman[34]	Log normal distribution of particle size.
-	0.52	Hinds[39]	Mass median aerodynamic diameter corrected to zero time Uncorrected diameter = .71 µm Geometric standard deviation = 1.37 Dilution of 10:1.

TABLE 4 (Continued). NUMBER CONCENTRATION AND AVERAGE SIZE OF PARTICLES CONTAINED IN TOBACCO SMOKE

Particle Number Concentration, per cm^3	Average Particle Diameter, µm	Reference	Comments
-	0.44	Hinds[39]	Uncorrected diameter = .51 µm Geometric standard deviation = 1.49 Dilution of 50:1.
-	0.37	Hinds[39]	Uncorrected diameter =.44 µm Geometric standard deviation = 1.31 Dilution of 700:1.
-	0.42	Porstendorfer[40]	Mean diameter Dilution of 10:1.
-	0.22	Porstendorfer[40]	Mean diameter Dilution of 3100:1.

The ratio between sidestream particulate matter emissions and mainstream particulate matter emissions has been reported by Rosanno[13] as 3:1. This sidestream to mainstream ratio varies from one component to another. Hemperley[14] reported it to be 3.5 for the total number of particles emitted per cigarette, 2.1 for tar, 1.8 for nicotine, 3.7 for benzo (a) pyrene. and 3.0 for pyrene. This indicates that the various components are probably not distributed equally throughout the entire size range of particles contained in cigarette smoke.

Hinds[39] reported that during measurements in indoor public places, the concentration of nicotine varied from 1 $\mu g/m^3$ (in a bus waiting room) to 10.3 $\mu g/m^3$ (in a cocktail lounge). From these data, the contribution of tobacco smoke to the concentration of particulate matter was estimated to vary between 40 and 400 $\mu g/m^3$, respectively. Hoegg[8] reported a particulate concentration of 16.65 mg/m^3 in a 25 m^3 test chamber resulting from the sidestream smoke of 3 cigarettes.

SECTION 3

EXPOSURES FROM SMALL INTERNAL COMBUSTION ENGINES AND CHARCOAL GRILLS

Unlike indoor domestic combustion sources, outdoor domestic combustion sources have not been studied or reported on to any significant extent. It was therefore necessary to design and implement an experimental program which would help to determine exposures to emissions from such sources. This section describes the experimental program and presents the results of the testing.

DESCRIPTION OF EXPERIMENTAL PROGRAM

Monitoring Equipment

The initial phase of the experimental program was to select and assemble the necessary monitoring equipment. The equipment had to be rugged, portable, compact, and capable of measuring exposures to CO, PM, and POM.

Several companies market devices that measure exposures to CO. After examining a variety of these instruments, it was decided to utilize the Ecolyzer 9000 CO Dosimeter for the experiments. This Dosimeter, marketed by Energetics Science, Inc., is a portable, pocket-size instrument that measures cumulative dosages of CO via a three-electrode electrochemical sensor. This sensor creates a minute electrical current in the presence of CO and supplies a stable signal proportional to the ambient CO concentrations. The dosages are stored internally until the Dosimeter is plugged into a readout unit which gives a digital display of the cumulative CO exposure in ppm-hrs. The device is 301.5 cm^3 in size, weighs 255 grams, and has an accuracy of $\pm$ 6% of the reading (according to the manufacturer).

With the CO Dosimeter selected, a means of measuring particulate matter and POM had to be incorporated into the sampling system. It was decided to use particulate filter cassettes which utilize 3.6 cm diameter, Millipore type HA, membrane filters. These filters can be weighed before and after the test to determine particulate loadings and they can also be analyzed by the fluorescent spot method[4,1] to determine POM exposures.

The last item necessary for the sampling system was a pump that would be portable and that would draw sufficient sampling air through the Dosimeter and the filter cassette. This presented a problem in that the Dosimeter requires a flow of only 100-120 ml/min., while a much higher flow is preferred through the filter in

order to obtain a measurable sample. The best arrangement proved to be a Bendix Super Sampler BDX 44 pump and a flow splitter. The pump is capable of a flow rate of 3000 ml/min. and weighs only 629 grams. By using a splitter with one leg containing a small glass capillary tube as a flow restriction, the system was able to draw 100 ml/min. through the Dosimeter and 2900 ml/min. through the filter. Calibration was performed by using the flowmeter that is an integral part of the pump along with a separate flowmeter included with the Ecolyzer equipment.

The total monitoring system thus consisted of a Bendix pump which attached to an operator's belt, an Ecolyzer CO Dosimeter which fit into a shirt pocket, and a particulate filter cassette which clipped on the outside of the shirt pocket. Figure 2 is a schematic of the sampling system.

Source Selection

There are several categories of domestic internal combustion devices commonly in use. These include push-type lawn mowers, riding mowers, chain saws, hedge trimmers, lawn edgers, snow blowers, and rototillers. Not all of these devices are used in most households. The objective of this program is to determine the exposures to the most common devices that a majority of the population would receive.

Two different methods were used to determine which devices are the most common. The literature has some published data on sales of small IC engines[42] and these data were utilized. For example, such data showed that the sales of push-type mowers were ten times as great as the sales of riding mowers. The other method was to distrubute a questionnaire among TRC employees asking them which devices they owned and used. Based on these two methods and discussions with the EPA, it was decided to test exposures to push-type lawn mowers and chain saws.

Similar reasoning was applied to the charcoal cooking category. There are a few different methods of igniting charcoal, but by far the most common is with charcoal lighter fluid and so this was the method selected to be tested.

Description of Field Tests - General

Each field test was conducted by the same operator using identical test procedures to eliminate unnecessary variables. Two sets of monitoring systems were utilized. One set was worn by the operator to record his exposures. The other set was situated in a nearby location that would be unaffected by the source being tested. The purpose of the second unit was to record the background levels of CO, PM, and POM.

At the start of each test, the Dosimeters were calibrated and cleared of any previous dosages. The following items were then recorded on a standardized data sheet:

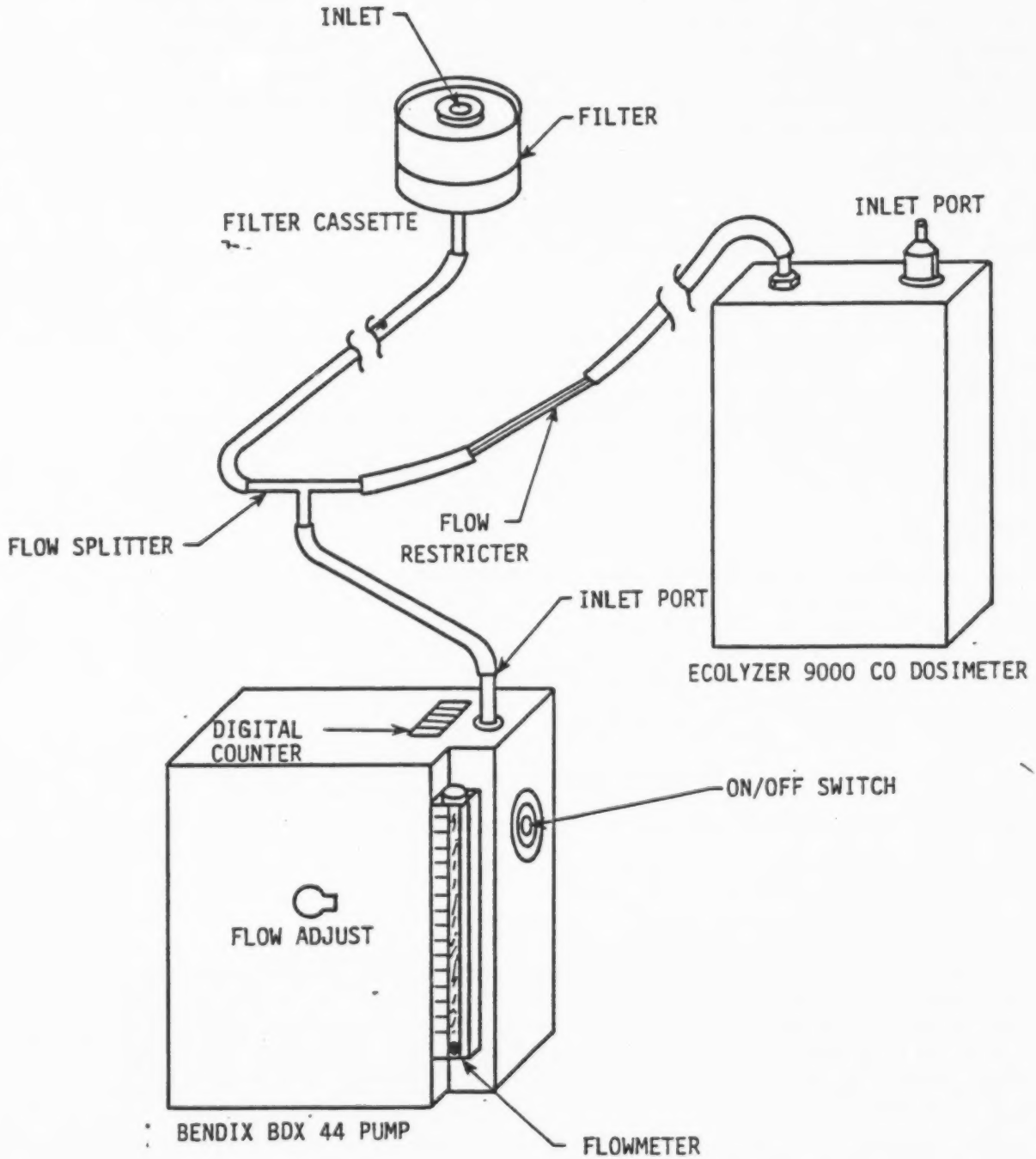


Figure 2. Schematic of Sampling System Used For Domestic Combustion Field Tests

- o Date of test
- o Type of source tested
- o Description of device
- o Meteorological conditions
- o Plot plan showing samplers and activity locations
- o Dosimeter numbers
- o Start time of test
- o Beginning pump counter and rotameter readings
- o Filter numbers

The monitoring systems were then positioned, the pumps turned on, and the activity was begun.

At the completion of the tests, the pumps were shut off and the following items were recorded on the data sheet:

- o Mode of operation (continuous or start/stop, fuel usage, etc.)
- o Finish time of test and total time source and pump were operating
- o Ending pump counter and rotameter readings
- o CO exposure readings
- o Narrative describing test and any unusual occurrences

The filter cassettes were wrapped in aluminum foil and stored in a refrigerator until they could be weighed and analyzed by TRC's Chemistry Lab. This type of filter handling was necessary to minimize degradation and loss of any polycyclic organic matter.

Description of Field Tests - Specific

A total of fifteen field tests were conducted to assess exposures to domestic combustion sources: six tests on lawn mowers, four tests on chain saws, and five tests on charcoal grills.

For four of the six lawn mowing field tests, the same lawn mower was utilized. This provided a measure of the repeatability of the results. All mowing was performed in a circular or square pattern so that the results would not be biased by wind direction. Table 5 provides the test conditions for this source category.

Four different chain saws were tested under a variety of conditions. The type and diameter of the wood that was cut varied considerably and the relative position of the operator to the sawing activity was also different in each case. Where possible, the operator was positioned so that emissions and sawdust were blown away from him. Table 6 presents the test conditions.

TABLE 5. DOMESTIC COMBUSTION FIELD TEST PARAMETERS - LAWN MOWERS

Test Number	1	2	3	4	5	6
Date of Test	10-15-79	10-16-79	10-17-79	10 19-79	10-23-79	10-25-79
Test Location	Manchester, CT	Wethersfield, CT	Glastonbury, CT	Wethersfield, CT	Cromwell, CT	Farmington, CT
Length of Test	1330-1430	1350-1450	1230-1430	1320-1420	1210-1310	1200-1330
Weather Conditions:						
Wind Speed	Gusty to 16-32 km/hr	~8 km/hr	Gusty to 16-32 km/hr	~8 km/hr	Gusty to 16 km/hr	Gusty to 24 km/hr
Wind Direction	SW	N-E	W-N	Variable	SE-SW	SW
Temperature	10°C	16°C	18°C	16°C	21°C	10°C
Cloud Cover	75%	10%	75%	100%	75%	100%
Mower Specifications:						
Manufacturer	Sears	-	Lawn Boy			
Model	-	Gran Prix-WDE 22	21 Deluxe-7620G			
Approximate Age	10 years	2 years	<1 year			
Horsepower	3.5	3.5	-	- Same as Test No. 3 with no grass catcher -		
Additional Information	Briggs & Stratton engine Exhaust to side Variable speed.	Briggs & Stratton engine Exhaust to side Variable speed. 148 cc at 3600 rpm.	2 cycle engine Exhaust down Single speed Grass catcher.			
Lawn Conditions	Grass 7-10 cm long Heavy leaf cover in spots.	Grass 5 cm long Some leaves Very dusty in spots.	Grass 7-10 cm long Heavy leaf cover in spots.	Grass 10-15 cm long and thick Some leaves.	Grass 5-7 cm long Heavy leaf cover in spots. Dusty in spots.	Grass 10-15 cm long and moist Heavy leaf cover in spots.
Additional Comments			Grass catcher attached but left unzipped. Tended to fill up in matter of minutes.			

TABLE 6. DOMESTIC COMBUSTION FIELD TEST PARAMETERS - CHAIN SAWS

Test Number	8	9	10	11
Date of Test	10-30-79	11-6-79	11-8-79	11-12-79
Test Location	Glastonbury, CT	Ellington, CT	E. Hampton, CT	E. Hampton, CT
Length of Test	1140-1210	1230-1330	1325-1425	1420-1520
Weather Conditions:				
Wind Speed	Gusty to 16-24 km/hr	8-16 km/hr	8-16 km/hr	< 8 km/hr
Wind Direction	N-NE	S	N-NW	S
Temperature	13°C	10°C	10°C	7°C
Cloud Cover	5%	100%	90%	100%
Chain Saw Specifications:				
Manufacturer	Stihl	McCulloch	Poulan	Echo
Model	015 AV	1-70	-	452 VL
Blade Length	35.6 cm	45.7 cm	40.6 cm	40.6 cm
Self-Oiling/Manual	Self-Oiling	Manual	Both	Self-Oiling
Approximate Age	2 years	10-15 years	Brand new	< 1 year
Description of Activity	Small branches (5-15 cm dia.) placed on cinder blocks (45 cm above ground) and cut up. Sawing took place in an open area.	Large logs (up to 40 cm dia.) placed on sawhorse (90 cm above ground) and cut up. Sawing took place in an open area.	Pallets and split logs cut up at ground level. Sawing took place adjacent to house.	Cut down a large tree (30-35 cm dia.) at a height of 180 cm above ground and then cut up limbs on ground. Sawing took place in an open area.
Additional Comments	Saw idling most of the time.	Large quantities of saw dust produced. Noticeable exhaust.	First time saw used. Operator directly over activity.	Large quantities of saw dust produced when tree cut down.

The testing of the charcoal grills presented a slight problem in that during a typical cooking activity, the operator may be near the grill for only a few minutes. For example, if chicken is being barbecued, the operator lights the coals, comes back to put on the chicken, comes back again to turn the chicken over, and then returns one final time to remove the food. The rest of the time he is removed from such close-up exposures. Such brief exposure duration does not allow time to obtain meaningful samples. It was thus decided to set up the monitoring system on a tripod at a location identical to the position a person cooking on the grill would naturally assume. This would be at breathing level, slightly upwind of the cooking activity to avoid smoke irritation. As in an actual cooking experience, smoke would occasionally impact the monitor due to variable wind gusts. The results obtained would thus provide a measure of the maximum exposure a person could experience if he stood over the grill the whole time cooking occurred. More realistic exposures could then be obtained by taking some fraction of the maximum exposures corresponding to the actual time spent near the grill.

Five charcoal grill tests were conducted. The first two tests recorded exposures during typical cooking activities (steak, chicken). The next two tests were designed to measure exposures from just the combustion of the charcoal with no cooking taking place. The final test was similar to the fourth test except hamburgers were cooked for a 20-minute period during the test. Readings of the CO exposures were taken at frequent intervals (every 30 minutes for test 13, every 15 minutes for tests 14 and 15) during these last three tests to determine the peak exposure periods. Table 7 presents the test conditions for this source category.

DATA AND LABORATORY ANALYSES PROCEDURES

Carbon Monoxide

Carbon monoxide exposures were obtained directly from the Dosimeters using the Readout at the conclusion of each field test. The Readout gives a digital reading of cumulative exposure in ppm-hrs. Division of this reading by the sampling time in hours results in a time-weighted average concentration. The ambient CO level, obtained from the background monitor, was subtracted from the CO reading obtained from the operator's monitor in order to get the actual exposure due solely to the activity being tested.

Particulate Matter

Prior to field testing, the Millipore filters were desiccated over silica gel in a glass desiccator for 24 hours. The filters were then removed one at a time from the desiccator and weighed to the nearest 0.01 mg on an analytical balance. After each filter weight was recorded, the filter was placed on its backing and inserted into the plastic sampling cassette. The inlet and outlet holes of the cassette were plugged with plastic stoppers. The completed sampling cassette was then marked with an identifying number and placed in a desiccator until ready for field use.

TABLE 7. DOMESTIC COMBUSTION FIELD TEST PARAMETERS - CHARCOAL GRILLS

Test Number	7	12	13	14	15
Date of Test	10-29-79	11-15-79	11-20-79	12-3-79	12-4-79
Test Location	Rocky Hill, CT	Rocky Hill, CT	Rocky Hill, CT	Manchester, CT	Manchester, CT
Length of Test	1840-1900	1120-1220	1325-1625	1205-1505	1115-1415
Weather Conditions:					
Wind Speed	≤8 km/hr	8-16 km/hr	16-24 km/hr	8-16 km/hr	16-24 km/hr
Wind Direction	S	W-SW	S-W	N-NW	N-E
Temperature	10°C	10°C	10°C	4°C	4°C
Cloud Cover	0%	50%	50%	0%	75%
Test Specifications:					
Type of Grill	Double Hibachi	Double Hibachi	Double Hibachi	24" Dia. Grill	24" Dia Grill
Charcoal Type	Kingsford	Kingsford	Kingsford	Kingsford	Kingsford
Lighter Fluid Type	Sunshine Lite	Sunshine Lite	Sunshine Lite	Sunshine Lite	Sunshine Lite
Approx. No. of Briquets	30	40	40	80	80
Food Cooked	Steak	Chicken/Potatoes	None	None	5 Hamburgers
Distance Between Monitor and Charcoal	61 cm	61 cm	61 cm	84 cm	84 cm
Additional Comments	Smoke affected monitor. Monitor started when steak placed on grill.	Smoke had little effect on monitor. Monitor started when chicken was placed on the grill.	Smoke slightly affected monitor. Monitor started when charcoal was lit. No cooking done - just charcoal combustion.	Smoke slightly affected monitor. Monitor started when charcoal was lit. No cooking done - just charcoal combustion.	Smoke slightly affected monitor. Monitor started when charcoal was lit. Hamburgers added after 45 min. and cooked for 20 min.

Upon completion of each field test, the sample cassette was removed from the sampling train and the inlet and outlet ports were plugged with the plastic stoppers. The cassettes were wrapped in aluminum foil and refrigerated until the laboratory was ready to analyze them. The refrigerated storage time was typically one to two days.

Upon receiving the samples in the laboratory, the aluminum foil wrapping and the plastic plugs were removed. The filter cassettes were then immediately placed in a desiccator. The desiccator was placed in a doubled, black plastic bag to exclude light and placed in a darkened cabinet at room temperature for 24 hours. After the desiccating period, the sample cassettes were removed one at a time. The cassette halves were carefully separated so as not to lose any particulate matter. The filter was removed from the cassette and weighed on an analytical balance. The difference between the initial and final weights then equals the total mass of the collected particulates. Dividing this weight by the sampling flow volume gives the concentration value.

Polycyclic Organic Matter

Once the filters were weighed, they were analyzed for the presence of POM by using the fluorescent spot technique as devised by Smith and Levins.[41] This method can be used to estimate the order of magnitude concentration of POM in samples.

The first step in this procedure is the extraction of the filters. After all glassware has been pre-rinsed twice with methylene chloride, the Millipore filters are placed in a 250 ml Erlenmeyer flask with 100 ml of methylene chloride. The flask is then placed on a swirler for 30 minutes. The liquid is carefully transferred to a 500 ml K-D set-up with a 4 ml calibrated concentrator and the extract evaporated to 500 µl. The extract is then transferred via Pasteur pipette to 3.5 ml glass vials (covered with aluminum foil) for storage.

Once the sample has been extracted and concentrated, it is ready for fluorescence detection via the spotting technique. An 11 cm circle of Whatman #42 filter paper showing no background fluorescence is selected. Using a template and sharp lead pencil, nine circles of 2.78 mm diameter are drawn in two rows. The solution to be spotted is added to the filter paper within two of the circles using a 1 µl hypodermic syringe. During this step, the filter is supported at the edges such that the area to be spotted does not touch any surface. The syringe is rinsed at least three times with methylene chloride to remove any possibility of cross contamination and then rinsed with one volume of the solution to be spotted. The syringe is filled with the solution to be spotted and the volume adjusted to 1 µl. The needle tip is touched to the center of the circle while depressing the plunger and blowing gently on the spot. This procedure is continued until all the material in the syringe has been added to the circle.

The sensitizer solution used for the technique is naphthalene at a concentration of 60 µg/µl in methylene chloride. Using a 1 µl syringe, 1 µl of

sensitizer is added to one of the spots containing the extracted filter solution and to one other spot. One of the remaining six spots is spotted with an unused filter extract in order to insure that there is no fluoresence inherent in the extract itself or the solvents. The other five spots contain various amounts of anthracene (1 ng, 10 ng, 100 ng, 1 µg and 10 µg) which are used for comparison purposes.

Once the spotting has been completed, the filter paper is placed in a Model C-70 Chromatovue ultraviolet cabinet which utilizes a 254 nm lamp source to expose the samples. The spots are then visually compared by the unaided eye within 10 minutes of the addition of the sensitizer. If the sample plus sensitizer spot fluoresces brighter than the spot with sensitizer alone, the presence of POM is indicated. Comparison with the anthracene concentrations gives an indication of the relative sample concentration.

RESULTS OF EXPERIMENTAL PROGRAM

Carbon Monoxide

The raw data and time-averaged CO concentrations obtained from the experimental program are presented in Table 8 for all three source categories. The last column presents the time-averaged concentrations which were calculated by subtracting the background Dosimeter reading from the source Dosimeter reading and dividing the result by the length of the test in hours.

The average CO concentrations obtained from the lawn mowing tests are quite consistent and fairly low, ranging from 1 to 5 ppm. The four tests that were conducted on the same mower (tests 3-6) show very good agreement with a range of 2.5 to 4 ppm. Some degree of consistency is expected since the operator of a lawn mower is always in the same position relative to the engine. Differences in the age and condition of the mower and the lawn conditions did not seem to produce any noticable variations in average CO concentrations.

The chain saw tests resulted in a large variation in CO exposures. The values obtained ranged from approximately 1 ppm-hr up to 36 ppm-hrs. The two smaller CO exposures (tests 8 and 11) were obtained during tests where the diameter of the wood was small, the chain saws were small, and the cutting took place in open areas with a crosswind. The value of 15 ppm was obtained using a very old large chain saw that had noticeable exhaust while cutting large diameter logs. The cutting took place with a crosswind. The highest value of 36 ppm (test 10) was produced during a test in which the operator was cutting up logs directly adjacent to a house. There was no crosswind and thus the exhaust rose straight up. In addition, the sawing took place at ground level with the operator directly over the operation. One other possible reason for the high concentration could be that this was the first time the saw was used and there could be excess emissions during an engine "break-in" period.

The charcoal grill tests, with one exception, resulted in fairly consistent average CO concentrations. The first test performed (number 7) may have been

TABLE 8. CARBON MONOXIDE RESULTS FROM THE EXPERIMENTAL TEST PROGRAM

Test Number	Type of Source Tested	Length of Test, min.	Receptor Dosimeter Reading, ppm-hrs	Background Dosimeter Reading, ppm-hrs	Time-Averaged CO Concentration, ppm	CO Concentration/ CO Ambient Air Quality Standard**
1	Lawn Mower	60	1	0	1	0.03
2	Lawn Mower	60	5	0	5	0.14
3	Lawn Mower	120	5	0	2.5	0.07
4	Lawn Mower	60	4	1	3	0.09
5	Lawn Mower	60	4	0	4	0.11
6	Lawn Mower	90	5	0	3.3	0.09
8	Chain Saw	30	<1	0	≈1	0.03
9	Chain Saw	60	15	0	15	0.43
10	Chain Saw	60	36	0	36	1.03
11	Chain Saw	60	4	0	4	0.11
7	Charcoal Grill	20	10	0	30*	0.86
12	Charcoal Grill	60	9	0	9*	0.26
13	Charcoal Grill	180	38	4	11.3*	0.32
14	Charcoal Grill	180	33	3	10*	0.29
15	Charcoal Grill	180	22	2	6.7*	0.19

*Maximum values based on continuous operator presence near grill.
**One-hour average CO standard = 35 ppm.

unduly influenced by large quantities of smoke impacting the sampler, thus producing the high CO level. A concentration of 9 ppm (test 12) was obtained while cooking chicken for one hour. The monitoring system was turned on approximately 30 minutes after the charcoal was ignited as this was when cooking was initiated. Tests 13-15 were all three-hour tests in which the sampling was begun when the charcoal was first ignited, rather than when cooking would be started. CO exposures were recorded at frequent intervals to determine peak concentration periods. The results, corrected for background, are plotted in Figure 3. Tests 13 and 14 were performed with no cooking taking place. The higher level of test 13 may be due to the position of the monitor relative to the burning charcoal. The monitor was only 61 cm from the charcoal during this test while it was 84 cm from the charcoal for test 14. Additionally, test 13 was performed in a more enclosed location while test 14 was out in the open with a better crosswind. Tests 14 and 15 were identical except for the cooking of hamburgers during test 15. The CO exposure measured during test 15 was lower than the exposure measured during test 14. This could be due to stronger crosswinds during this test, thus reducing the impact of the emissions on the monitor. It could also be due to reduced oxygen from the fat covering the charcoal and the hamburgers on the grill causing blockage, thus limiting CO production.

It should be noted that the above discussion on charcoal grill exposures is based on maximum operator exposure. As mentioned previously, actual exposures would be some percentage of this value corresponding to the time the person is actually in front of the grill. To get a feel for a more realistic exposure to CO from charcoal cooking, assume that the operator is exposed to the emissions for 10 minutes out of an hour of cooking. Using a maximum exposure of 12 ppm-hrs, the operator would be actually exposed to about 2 ppm-hrs during the activity.

Particulate Matter

The results of the particulate analyses are given in Table 9 for all three source categories. No results are given for tests 5 and 7 because the final weighings of the source and background filters were performed on different days and, thus, some humidity effects occurred. A final weighing could not be performed for one of the filters of test 3 due to a small piece of filter destroyed during handling. The flow volumes given in column four of the table were obtained from the rotameter readings on the Bendix pumps.

The particulate concentrations obtained from the lawn mower tests range from 310 to 1600 $\mu g/m^3$. The two low values (310 and 400 $\mu g/m^3$) were obtained using the same mower. This particular mower had a smaller engine than the mowers of tests 1 and 2 and it also had downward exhaust, rather than to the side as in the first two test mowers. Grass particles were visible on some of the filters.

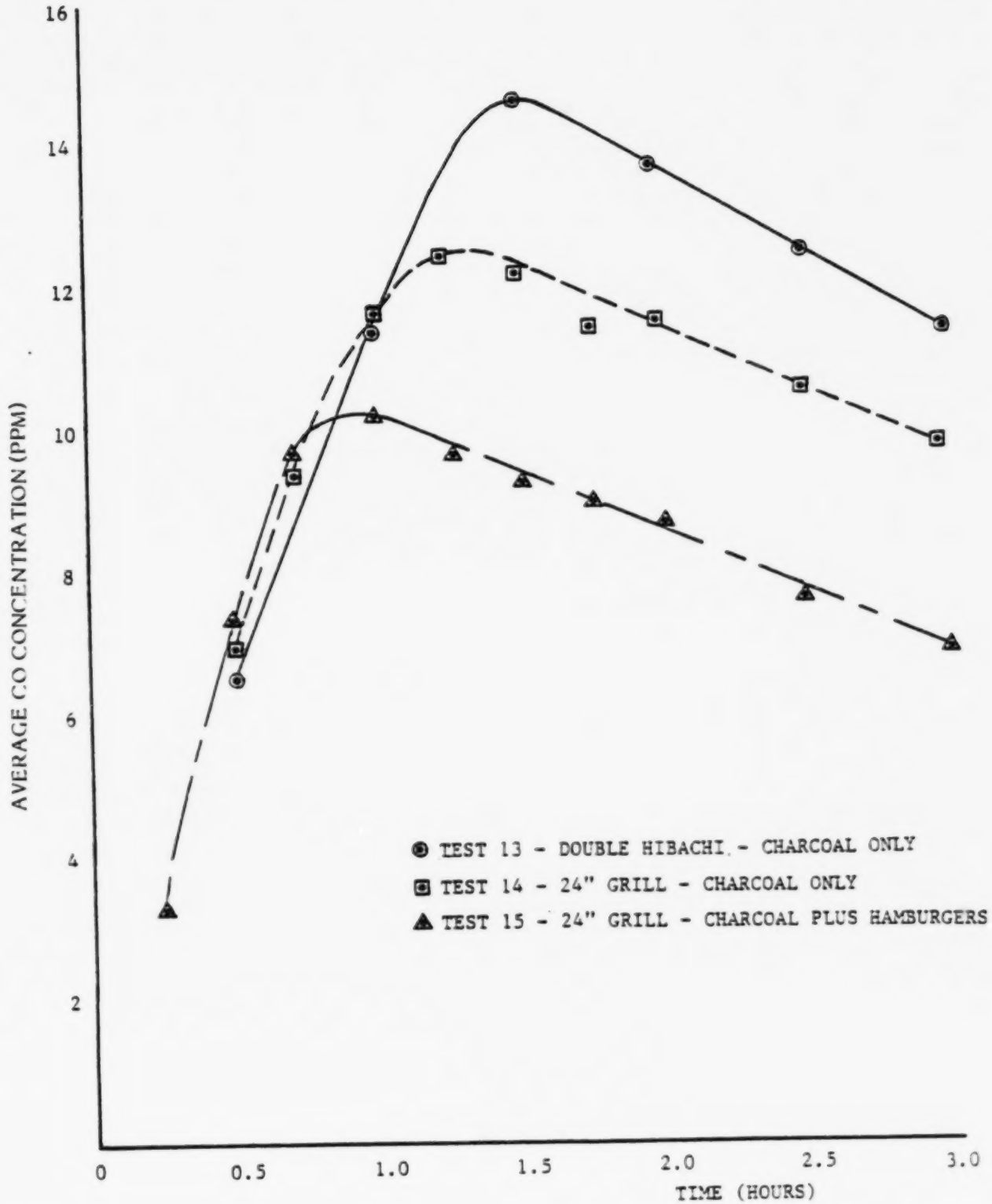


Figure 3. Average CO Concentrations from Charcoal Grills as a Function of Time

TABLE 9. PARTICULATE RESULTS FROM THE EXPERIMENTAL TEST PROGRAM

Test Number	Type of Source Tested	Difference Between Receptor Filter Weight and Background Filter Weight, µg	Total Flow Volume Through Filter, m^3	Particulate Concentration, $\mu g/m^3$	Particulate Concentration/ Secondary TSP Ambient Air Quality Standard**
1	Lawn Mower	280	0.17	1600	10.7
2	Lawn Mower	200	0.17	1200	8.0
3	Lawn Mower	--	0.35	-	
4	Lawn Mower	70	0.17	400	2.7
5	Lawn Mower	--	0.17	400	2.7
6	Lawn Mower	80	0.26	310	2.1
8	Chain Saw	40	0.09	440	2.9
9	Chain Saw	330	0.17	1900	12.7
10	Chain Saw	820	0.17	4800	32.0
11	Chain Saw	920	0.17	5400	36.0
7	Charcoal Grill	--	0.06	-	-
12	Charcoal Grill	10	0.17	60	0.4
13	Charcoal Grill	-10*	0.52		-
14	Charcoal Grill	-30*	0.52		-
15	Charcoal Grill	-40*	0.52		-

*Negative values are probably the result of weighing balance sensitivity.
**24-hour secondary TSP standard = 150 $\mu g/m^3$.

The concentrations obtained from the chain saw field tests showed a wide variety of values, ranging from 440 to 5400 $\mu g/m^3$. The highest value was obtained under conditions in which the operator himself was covered with sawdust following the felling of a tree. Visible sawdust particles were seen on the filters following the tests.

There were essentially no particulate exposures due to the charcoal grilling activities. The results obtained from the sources were all very near to the levels recorded by the background monitors and thus no significant particulate exposure seems evident from this source category.

Polycyclic Organic Matter

All of the particulate filters were tested for the presence of POM using the fluorescent spot technique. As discussed previously, this technique is based on comparing the fluorescence of the prepared samples with that of known concentrations of anthracene (sensitized with naphthlene). The lowest detectible amount is 1 ng. The next level of comparison is 10 ng.

Based on this technique, all of the particulate filters displayed levels of POM that were approximately equal to or lower than the lowest detectible limit of 1 ng. None of the filters displayed fluorescence that would be comparable to the 10 ng level.

To provide insight into the levels of POM expected and the sensitivity of the POM measurements, some brief calculations can be performed. The lowest detectible amount, 1 ng, would correspond to a concentration of approximately 5 ng/m^3 based on the hourly flowrate through the particulate filter. To determine what levels of POM are expected, published information on automobile and small utility engine exhaust can be used in conjunction with the lawn mowing results of this project. Santodonato et al[42] present information on exhaust emissions from gasoline automobiles. According to these data, the ratio of particulate to BaP (used as an index for POM) emission rates is very roughly 250 mg/mile to 5 μg/mile or 50,000:1. Since no data could be found on emissions of BaP from small utility engines, it will be assumed that this ratio stays the same for small engine exhaust. The ratio of CO to particulate emission rates for 4-stroke lawn and garden engines can be obtained from Hane and Springer[43] as approximately 100:1. Combining these two values than gives a ratio for CO/BaP of about 5×10^6:1. Using a CO concentration of 5 ppm for lawn mowing, a concentration of about 1 ng/m^3 would be expected for POM. This level is below the lowest detectible level of about 5 ng/m^3. Therefore, the results obtained using the fluorescent spot technique seem reasonable.

SECTION 4

COMPARISON OF EXPOSURES

One objective of this project was to compare the exposures obtained through the literature search and the field tests with those from more conventional sources of pollutants, such as automobile exhaust. To do this properly, the exposures should be in terms of "typical" exposures based on source usage patterns. The following subsections establish typical exposures from domestic combustion sources and compare them with exposures from other sources.

"TYPICAL" USAGE OF DOMESTIC COMBUSTION SOURCES

To obtain information on the usage patterns of the various combustion sources, a questionnaire was circulated among all TRC employees. Table 10 summarizes the results of this questionnaire for lawn mowers, chain saws, and charcoal grills. The literature also contained some information on usage patterns. For lawn mowers, Hare and Springer[43] presented a value of 40 hours/year (based on 18 times/year), Zinger and Hecker[44] used 50 hours/year in their calculations, and Donahue et al[45] gave a range of 30-70 hours/year. Only one value could be found for chain saws and that was a rough estimate of 3-4 hours/year.[45] However, this report was produced at a time when home heating by wood stoves was not nearly as common as it is today. No information on charcoal grill usage could be found in the literature.

Based on the information presented in Table 10 and the literature, the following values were chosen as rough estimates for source usage for individuals owning and operating these devices:

Lawn mowers:	40 hours/year
Chain saws:	70 hours/year
Charcoal grills:	20 hours/year

It should be noted that these are average values for the New England area. In southern areas, it is logical to assume that the use of lawn mowers and grills could increase proportionally to the duration of warm weather and the use of chain saws would decrease. For national values, the following gross estimates will be used for individuals owning such devices:

TABLE 10. SOURCE USAGE PATTERNS BASED ON TRC QUESTIONNAIRES

Type of Source	Sample Size	Hours/Use		Uses/Year		Hours/Year	
		Arithmetic Mean	Range	Arithmetic Mean	Range	Arithmetic Mean	Range
Lawn Mower	36	1.8	0.5-6	16	8-30	29	4-90
Chain Saw	15	2.6	1-8	28	2-100	72	2-350
Charcoal Grill	29	0.7	0.3-1.5	25	3-100	18	1.5-60

Lawn mowers:	50 hours/year
Chain saws:	30 hours/year
Charcoal grills:	40 hours/year

For the case of gas stove usage, only a very rough estimate can be made. Assume that a person uses a gas stove six times per week for meals at an average of one hour per time and twice a day for heating water or warming leftovers at about fifteen minutes per time. This sums up to about 500 hours per year that the stove is on. This could be further analyzed by considering that several burners (and possibly the oven) are usually on while preparing meals while only one burner is on for heating water. It has been shown[3] that emissions increase with an increase in burner usage. However, the 500 hour estimate is very crude to begin with and further refinement would be meaningless.

Too many variables exist to estimate yearly exposures to sidestream smoke.

"TYPICAL" EXPOSURES TO DOMESTIC COMBUSTION SOURCES

Based on the results of the experimental test program, the literature search, and the usage patterns developed above, "typical" exposures to domestic combustion sources can be established. It is realized that the values obtained will be very crude due to the limited number of tests, the scarcity of literature information, and the rough assumptions on usage; however, the values will provide "ball park" estimates that can be used for comparison with exposures from other combustion sources.

Carbon Monoxide

Table 11 presents the "typical" exposures to carbon monoxide for New England and national usage assumptions. The values given for average exposure (column 2) were selected as follows: the lawn mower exposures varied from 1 to 5 ppm-hrs, so a value of 3 ppm-hrs was chosen; the chain saw exposures were quite varied but a value of 10 ppm-hrs was felt to be representative; a value of 2 ppm-hrs for charcoal cooking was selected based on the arguments presented in the previous section of this report. The study by Yocom et al[1] showed that the CO exposure was approximately 5 ppm-hrs during gas stove operation (see Figure 1) and so this value was used. It is also assumed that the person using the stove remains in the kitchen the entire time the stove is "on". As for sidestream smoke, not enough information is available to determine "typical" exposures as there are just too many variables.

TABLE 11. "TYPICAL" EXPOSURES TO CARBON MONOXIDE FROM DOMESTIC COMBUSTION SOURCES

Type of Source	"Typical" Hourly CO Exposure, ppm-hrs	Assumed Usage Per Year, hrs.		Estimated CO Exposure Per Year, ppm-hrs	
		New England	Nation	New England	Nation
Lawn Mower	3	40	50	120	150
Chain Saw	10	70	30	700	300
Charcoal Grill	2	20	40	40	80
Gas Stove	5	500	500	2500	2500

Particulate Matter

Table 12 presents the "typical" exposures to particulate emissions for both the New England and national usage assumptions. The average concentrations for one hour presented in column 2 were obtained as follows: for lawn mowers, the results for the three different types of mowers were averaged to obtain a value of 1000 $\mu g/m^3$; for chain saws, all four values were averaged to obtain 3100 $\mu g/m^3$. No significant value could be obtained for the charcoal category and thus an hourly concentration of zero is shown. Not enough literature information exists to establish estimates of particulate exposures from gas stoves and sidestream smoke.

Polycyclic Organic Matter

Since no significant amounts of POM were detected in any of the samples (i.e., all levels were equal to or less than the lowest detectible amount of 1 ng), no "typical" exposures can be determined.

COMPARISON OF EXPOSURES

Having established some "typical" exposures from domestic combustion sources, the pollutant levels can now be compared with exposures from other sources of CO, PM, and POM. Comparisons can also be made with the national standards.

Carbon Monoxide

The national ambient air quality standards for carbon monoxide are a one-hour average of 35 ppm and an eight-hour average of 9 ppm. Of the three types of domestic combustion devices tested during the experimental program, only chain saws appear to result in exposures comparable to exposures encountered in non-attainment situations. While the average chain saw CO concentration was approximately 10 ppm, one test resulted in a one-hour average concentration of 36 ppm. The eight-hour standard would not normally apply because domestic combustion activities are rarely performed for this length of time.

When comparing the exposures obtained from domestic activities with those from other activities, the domestic exposures seem quite minor. Commuting activities result in large CO exposures. Numerous studies have been performed in which CO exposures have been measured while commuting to and from work. Cortese and Spengler[46] used CO Ecolyzers in obtaining exposure data on 62 non-smokers, each carrying the monitors for a 3 to 5 day period during commuting and work activities. Mean one-hour concentrations of 5 to 20 ppm were obtained, with several hourly readings greater than 35 ppm. Other studies have recorded average levels up to 54 ppm, with peaks to 120 ppm.[47] Szalai[48] reported that the typical heads-of-households in 44 cities in the United States spend an average of nearly an hour and a half in travel per day or approximately 540 hours per year.

TABLE 12. "TYPICAL" EXPOSURES TO PARTICULATE MATTER FROM DOMESTIC COMBUSTION SOURCES

Type of Source	"Typical" Particulate Concentration, $\mu g/m^3$	Assumed Usage Per Year, hrs		Estimated Particulate Exposure Per Year, $\mu g/m^3$-hrs	
		New England	Nation	New England	Nation
Lawn Mower	1000	40	50	4000	5000
Chain Saw	3100	70	30	21700	9300
Charcoal Grill	0	20	40	0	0

Using an average CO concentration of 15 ppm results in 8100 ppm-hrs per year. Comparing this number with the values presented in Table 10 shows the relatively minor CO impact of domestic combustion sources on humans.

Particulate and Polyclyclic Organic Matter

It is not particularly meaningful to compare the particulate exposures obtained from the domestic combustion tests to those from other sources and, in fact, such comparisons could be very misleading. The particulate exposures obtained were based on the total weight of material found on the filters. Size analyses were not performed and it was evident that large portions of the weight were due to very large particles of either sawdust or grass. Such particles are well outside the inhalable size range (<15 μm in diameter) of particles which is of primary interest to EPA.

Only one study could be found which reported POM (or PAH) data that could be used for comparison purposes. Bridbord et al[49] used benzo(a) pyrene (BaP) as an index compound for PAH in establishing exposures. They recognized that to the extent that polynuclear aromatic compounds besides BaP are also present, BaP represents a poor surrogate for this purpose. Unfortunately, better data were generally not available. Their results showed that a one pack per day smoker of unfiltered cigarettes would inhale about 0.7 μg of BaP each day. The level was 0.4 μg for filtered cigarette smokers. They also reported BaP indoor concentrations ranging from 0.3 to 0.14 $\mu g/m^3$ in a restuarant. In some of their calculations they assumed ambient BaP levels in urban air of 0.002 $\mu g/m^3$. The results of the domestic combustion tests showed levels of POM less than or equal to 1 ng on the test filter. For a flow volume of 0.2 m^3, this would result in less than or equal to 0.005 $\mu g/m^3$ which is well below the levels presented by Bridbord et al for cigarette smoking.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

As a result of the literature review on indoor domestic combustion sources and the experimental program on small internal combustion devices and charcoal grills, several significant conclusions can be drawn regarding exposures to CO, PM, and POM from such devices. These conclusions are presented below.

- Charcoal cooking results in essentially no significant exposures to PM and POM and only very minor exposures to CO due to the limited time an operator is actually near the activity. In actuality, an operator may be better off standing near the grill than returning indoors to a room full of smokers.

- The combustion of charcoal alone, with no cooking taking place, seems to produce peak CO concentrations from 45 minutes to 90 minutes after the charcoal is ignited.

- Lawn mowing results in very low CO (approximately 3 ppm-hrs) and POM exposures. Particulate exposures were noted, primarily due to grass clippings and soil dust on the filters.

- CO exposures from lawn mowing seem to be independent of lawn and mower conditions, possibly due to the distance between the operator and the engine exhaust.

- Chain sawing can lead to significant levels of CO (one test resulted in 36 ppm for one hour) depending on crosswind, wood size, chain saw type and condition, and operator position. It is best to do the sawing in the open where a crossflow of wind can limit the exposure to the exhaust.

- Chain sawing results in significant particulate exposure (up to 36 times the secondary ambient standard), most likely due to sawdust. POM exposures were not detected.

- CO concentrations from gas stove cooking are on the order of 5 ppm for one hour. Particulate and POM exposures could not be readily determined from the literature.

- Sidestream smoke can lead to relatively high CO levels, but so many different study and reporting methods exist in the literature that quantification is not really possible. Even less information is available for particulate and POM.

- The exposures from domestic combustion sources seem to be of minor importance when compared with exposures from other sources, such as traffic. While one-hour exposures may be comparable in some cases, yearly exposures are vastly different due to the limited use of such devices as lawn mowers when compared with the time spent by most people in commuting to work.

RECOMMENDATIONS

This project can essentially be viewed as a screening study for domestic combustion sources. Many variables exist that could affect exposures and only a few could be examined during the test program. For example, it has been postulated that lawn mower emissions and exposures can be dependent on load factor, engine size, grass height, presence of leaves and dust on lawn, moisture of grass, engine air-fuel ratio, direction of exhaust, use of grass catcher, air temperature, wind speed, etc. The influence of these variables could obviously not be assessed in five or six field tests. However, this project did lead to some interesting conclusions and recommendations can be made for future investigations. These recommendations are presented below.

- Chain sawing should be investigated further due to the possibly high exposure levels that can result from such activity. This should be an area of increasing interest due to the increased usage of such devices in these times of home heating by wood stoves.

- Other domestic combustion devices that may be used in non-ventilated areas and/or close to the face of the operator should be identified and investigated.

- Short-term surges that might produce high levels of pollutants, such as charcoal ignition and engine start-up, should be investigated further. An operator is normally closer to a lawn mower or chain saw engine when starting it than when it is running.

- Indoor air quality is becoming increasingly important as homes become more energy efficient. Further experimental testing should be performed to determine exposures resulting from gas cooking, sidestream smoke, and other indoor sources of pollution. The data presented in the literature are not adequate.

- Indoor air quality measurements should be made in homes using wood and coal space heating equipment. The measurements should be made

across a population of users sufficient to describe the spectrum of equipment type, installation adequacy, and operating procedures.

- Further work is needed in defining the size and chemical characteristics of particulates generated by domestic combustion sources.

- A different method for the capture of the particulate matter and POM should be examined and compared to the one used for this study. A pump/cassette combination that would obtain a larger air sample volume might improve the accuracy of the results.

- CO Dosimeters should be used for future experiments. These devices proved to be accurate, easy to use, rugged, portable, and highly economical with regard to the time needed to apply them.

- Analyses or tests should be performed to determine if CO exposures as measured with the Dosimeter can be used as an index of exposure to other combustion related pollutants (e.g., combustion generated particulate matter and POM.)

SECTION 6

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